HYPERSPECTRAL IMAGING: A POTENTIAL TOOL FOR IMPROVING WEED AND HERBICIDE MANAGEMENT

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ABSTRACT

Precision management of agricultural inputs such as herbicides for weed control is crucial to ensure profitable farms and long-term sustainability of the land. There is now a range of information tools that the farmers can avail themselves of, including Yield Monitors, Global Positioning Systems (GPS), Geographic Information Systems (GIS), Variable Rate Technology (VRT), and Hyperspectral Remote Sensing, all of which can be placed under the label of Precision Agriculture.

This documentation addresses the effective, economical, and responsible integration of Hyperspectral Remote Sensing and Precision Agriculture technologies for use in small to medium sized farming operations for weed and herbicide management. In a test of the utility of such data, we have collected several inter-dependent data sets at an experimental farm on Maryland's Eastern Shore during the 1999 growing season, focusing on corn and soybeans. These data included: hyperspectral image data; ground feature differential GPS data; geo-located spectral measurements at ground level; and a database of field inputs and costs. Whether these technologies when used as weed and herbicide management tools can provide valuable information to a farmer for both short and long term decision making at a cost that is worth the investment remains a question. This paper describes the methods of data collection and analysis including preliminary results and lessons learned.

Keywords: Precision Agriculture, Hyperspectral, Remote Sensing, Weeds, Herbicide, Economics

INTRODUCTION

Importance of Weed Management

Precision management of agricultural inputs such as herbicides for weed control is crucial to ensure profitable farms and long-term sustainability of the land. The timeliness of weed management is also vital as crop yields are most influenced by weed status during the first two to three weeks after emergence for most crops. The effect of a single weed on yields can be seen in Table 1 for some sample weeds in crops.

Table 1. Effect of a single weed on yield. [Ross and Lembi, 1999]

Weed	Crop	Weed Density	% Yield Reduction
Giant Foxtail	Soybeans	1 weed/ft^2	13
Giant Foxtail	Corn	1 weed/ft^2	7
Velvetleaf	Soybeans	1 weed/3 ft^2	34
Sicklepod	Soybeans	1 weed/ft^2	30
Common Cocklebur	Soybeans	1 weed/ft^2	87
Giant Ragweed	Soybeans	1 weed/15 ft^2	46-52
Hemp Dogbane	Corn	1 weed/ft^2	15
Wild Oats	Wheat	1 weed/ft^2	11
Canada Thistle	Wheat	1 weed/3 ft^2	60

Thus, timing of weed and crop emergence is very important as early season competition has more impact than late-season pressures. Controlling weeds early is also the best way to control future weed populations as well. Weeds can produce very large numbers of seeds per individual plant, 34,000 per plant in Green Foxtail and 117,000 in each Pigweed plant for example. The longevity of these seeds when buried in the soil is astounding: seeds produced by the broadleaf weed Velvetleaf can survive for 40 years just beneath the surface. [Ross and Lembi, 1999] Controlling weeds before they reach their reproductive stage is therefore crucial to long-term weed management.

Because unnecessary inputs are costly to both farms and the environment, precision agriculture technologies and management practices including Hyperspectral Remote Sensing, the Global Positioning System (GPS), Geographic Information Systems (GIS), and Variable Rate Technologies (VRT) are growing more important on farms large and small. In addition, government regulations are beginning to require detailed reports of input characteristics such as type, amount, and time of application.

However, whether hyperspectral image products and the integration of these technologies can help farmers improve on thin profit margins while at the same time minimizing adverse effects on the environment remains under question.

Hyperspectral Remote Sensing and Precision Herbicide Management

Field scouting is currently the single best method to develop weed management plans. The knowledge and experience of a farmer or consultant in the field is an indispensable advantage in the fight against weeds. Scouts can closely monitor the timing of weed and crop emergence, pest populations, and any other specific request for field and crop information. The down side is that scouting every single acre of a farm is extremely time consuming and costly.

This is where advances in remote sensing technologies are beginning to play an increasing role in agriculture. The characteristics of most well known remote sensing satellites like Landsat are very effective for monitoring general vegetation health and progress of crops in medium to large fields (50-plus acres), but monitoring weeds is extremely difficult. Satellites like Landsat simply cannot "see" weeds in fields. The spatial resolution, or the area of the ground represented as a single unit (i.e. 30m by 30m), is simply too coarse in these systems. This is especially true in regions like the Delmarva (Delaware, Maryland, Virginia) where fields are typically small and irregularly shaped. Recent work at Chesapeake Farms in Chestertown, Maryland provides a good example of such field geometry. Figure 1 illustrates the difficulty of mapping an irregularly shaped 7.5 acre corn field (Field 51).

Figure 1. 28.5m resolution Landsat compared with 2m airborne imagery.

The image on the right is a late May 30m resolution Landsat image of Field 51. On the left is also a May image for Field 51, as recorded by the Airborne Imaging Spectroradiometer for Applications (AISA) Hyperspectral System (http://www.specim.fi) at 2m ground resolution. Not only is the shape of Field 51 difficult to make out in the Landsat image but any evidence of weeds is impossible to delineate visually and very difficult using computer recognition techniques.

To effectively implement precision weed management strategies, highly accurate digital mapping of weed infestations within fields via scouting, GPS, GIS, and Remote Sensing technologies will be necessary to take full advantage of site-specific VRT systems. When combined, these tools can increase weed control efficiency and reduce herbicide use and residues, thereby avoiding excess applications that lead to increased costs, potential herbicide resistance in the field, and runoff into the environment.

OBJECTIVES AND RESEARCH QUESTIONS

The primary objective was to demonstrate the ability of hyperspectral remote sensing data to provide information on weed location and species so that herbicide applications are timely, appropriate, economical, and environmentally responsible. The investigation was primarily focused on the following questions:

- *Can hyperspectral data provide the required spatial, temporal, and radiometric accuracy for use in site-specific agriculture in particular for rapidly identifying weed infestations early in the growing season?*

- *If the first question proves true, then can the end-to-end process be carried out in a manner that will provide net economic benefit to the farmer?*

STUDY SITE DESCRIPTION

Hyperspectral flights and fieldwork were conducted at Chesapeake Farms (http://www.dupont.com/ag/chesapeakefarms) on the Delmarva Peninsula near the town of Rock Hall, Maryland on May 28, July 8, and August 3, 1999. The primary crops investigated were soybeans and corn, although many other crops exist.

Chesapeake Farms is devoted to the development, evaluation, and demonstration of advanced agricultural practices and wildlife management techniques, which are designed to be environmentally sound, productive, economically viable and socially acceptable. The Sustainable Agriculture Project at Chesapeake Farms addresses how farmers can be successful today while preparing to meet tomorrow's challenges.

This commitment to responsible, forward-thinking agricultural management practices provides the foundation for a strong relationship with the Applied Information Sciences Branch (AISB), Code 935, at the Goddard Space Flight Center (http://sdcd.gsfc.nasa.gov/ISTO/code935/cube.shtml).

The AISB is working towards development and demonstration of an end-to-end capability to receive, process, and distribute complex imagery and associated information products to large numbers of public sector users in near real-time.

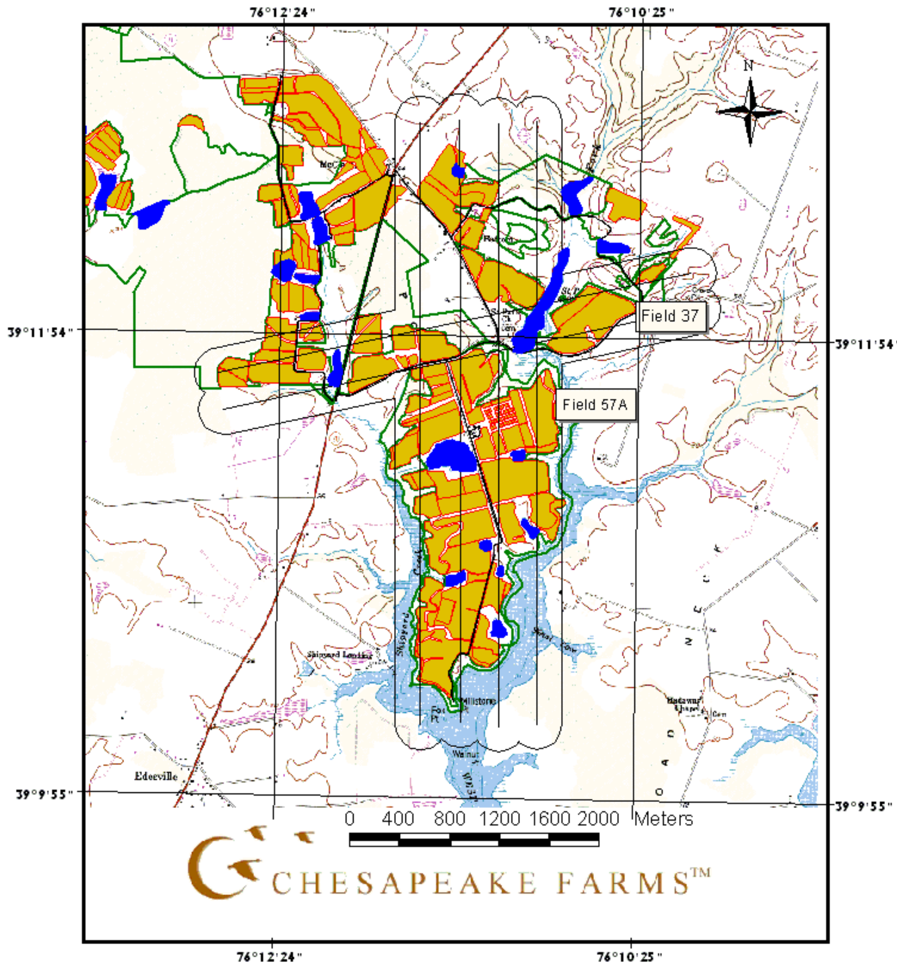

Figure 2. Map including flight plan for Chesapeake Farms

METHODS OF DATA COLLECTION

The AISA sensor

Field experiments were conducted coordinating the Airborne Imaging Spectrometer for Applications (AISA) sensor flown aboard a twin engine Navaho aircraft by 3DI (http://www.3dillc.com) of Easton, Maryland with teams on the ground collecting radiometric data.

The sensor has a spectral range of 430 to 900 nm and a swath width of 286 pixels that is imaged at a spatial resolution of 1m, 2m, and 3m for an aircraft flying at 1 km, 2 km, and 3 km respectively. In addition, simultaneous downwelling irradiance is measured. The instrument orientation is monitored by an Inertial Measurement Unit (IMU), and its position is recorded by differential GPS. The data was georectified and processed to both at-sensor radiance measurements, and to at sensor reflectance, by ratioing the upwelling radiance to the downwelling radiance.

Atmospheric Correction

An important part of applying hyperspectral data to precision farming will be monitoring temporal changes in spectral properties as an indicator of crop health. This requires that the hyperspectral imagery be transformed into reflectance spectra, which is an intrinsic property on the surface independent of solar illumination and atmospheric effects.

To perform atmospheric correction and subsequent conversion to reflectance, we have used the *three-band method* of [Gao et. al., 1993] [Gao et. al., 1997] as implemented in his ATREM LINE code which he has made available to us. This code explicitly estimates the gaseous water content in the atmosphere on a pixel by pixel basis from water absorption bands and uses scene estimates for aerosol and ozone. The absorption of the atmosphere is modeled by a line by line model for the atmospheric gases and takes into account the scattering in the atmosphere. Thus this code can be adapted to the AISA instrument, which in our work has spectral resolution around 7 nm.

Because of the limited spectral coverage of AISA, from 400 nm to 900 nm the only water absorption band that can be used is the one at 818 nm. To assess the atmospheric correction we used 2m resolution data close to solar noon, in which a "bright" road was present. No visible clouds were present at the time of the measurements. Ground radiometer measurements were taken 13 minutes after the aircraft passed over the road.

Fieldwork and Ground Truth Measurements

Location of sampling points and field boundaries were made with a Trimble Pro XR Differential GPS system. Differential signals from regional Coast Guard towers were used in real-time mode. Extensive fieldwork utilizing the differential GPS was conducted to map weed infestations in the study fields. This fieldwork noted each weed species and density of weeds within a given area. (See Figure 3) These areas were then delineated with the GPS to derive truth and training information for classifications and accuracy assessments.

Three Analytical Spectral Devices hand held radiometers; two model PS2's and one model FR (http://www.asdi.com) were used for the ground truth measurements of upwelling radiance and reflectance. Portable stands seen in Figure 4 were designed to hold the field radiometer heads and a spectralon panel (at a fixed distance from the head) for reflectance measurements. With the stands, spectral measurements at varying heights up to 2m over ground samples could be made. In addition, a Microtops 2 (http://www.solar.com) portable sun photometer was used to gather aerosol optical thickness measurements at regular intervals during the flights.

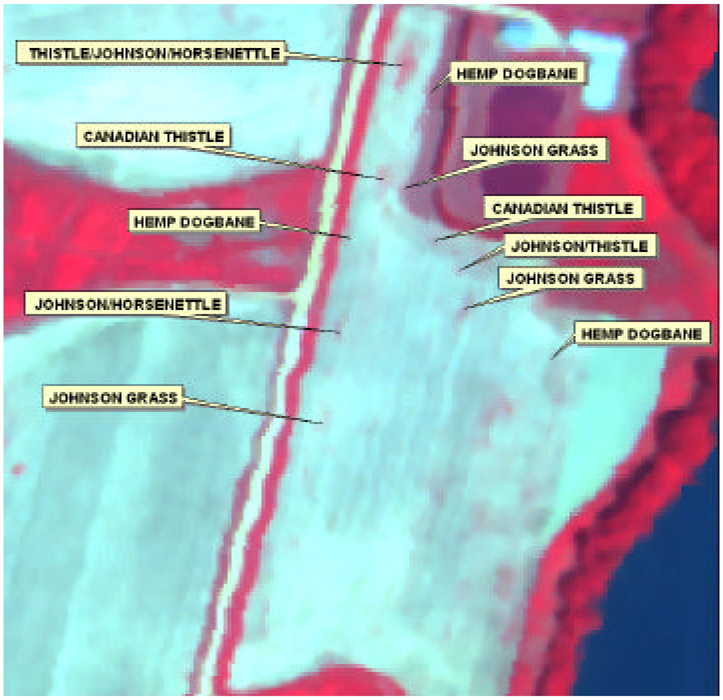

Figure 3. Sample Field 51 weed scouting map.

Figure 4. Portable stand in use with spectralon panel.

Delineation of Weed Infestations

Early detection of weeds through remote sensing can be an important tool to a farmer for improving crop yield, and if variable rate equipment for herbicide application is available for reducing costs and reducing environmental impact. The following May 1999 AISA images of Field 51 show the results of algorithms that can map weed density.

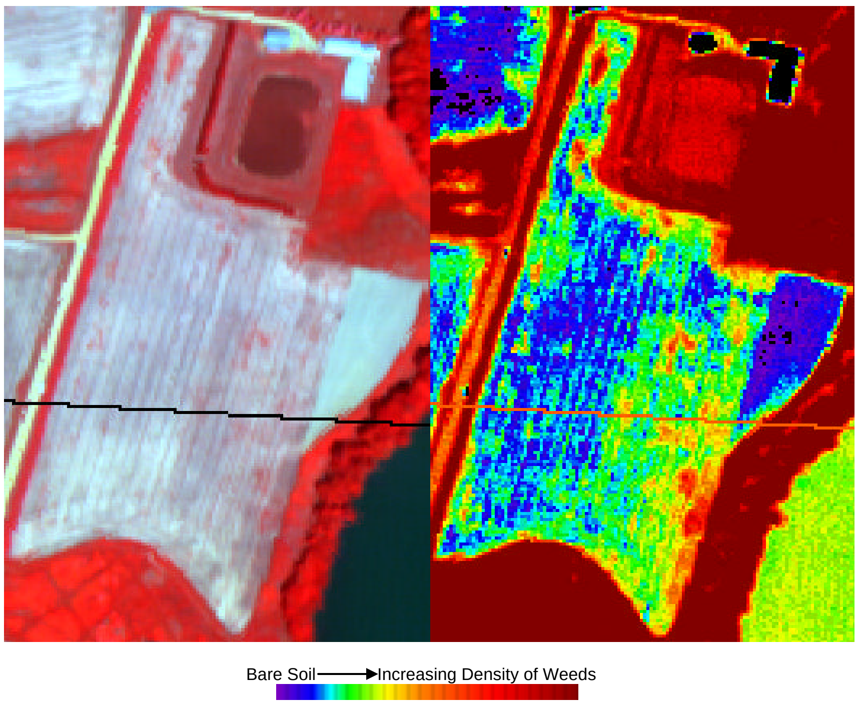

Figure 5: Minimum Noise Fraction highlighting weed density in a corn field at early emergence. Derived from 2m AISA data from May 28, 1999.

The images in Figure 5 show the results of a minimum noise fraction (MNF) [Boardman and Kruse, 1994] classification. The algorithm was applied to apparent reflectance data at 2m resolution from May 28, 1999. Within the field, colors from blue to red show areas of increasing weed density in the no-till cornfield. Notice the extreme right side of the field in consistent blue showing a lack of weed infestations. This area was tilled and planted with warm season grasses just prior to the hyperspectral flight. This map can easily be converted into a "Spray/Do Not Spray" map for VRT applications. It can be seen that the processed hyperspectral imagery provides a useful tool for the early detection of weeds.

Weed Species Detection

Using imagery to pinpoint where weeds are in the field is only the first step. Effective weed control also involves management of diverse populations of weed species. Therefore species detection is also a vital component of weed management plans employing remotely sensed data. Studies on weed species identification using multispectral data have not proved to be reliably successful. The limited spectral resolution of these systems is often compounded by their typically poor spatial resolution.

The increased number of bands in the AISA data improves our ability to see very small differences in the shape of the curve. The 20 to 45 bands used in the 1m to 3m data are placed at very specific points along the electromagnetic spectrum to look for specific signature characteristics. Areas on the graph where the signature drops to zero are where bands are not located. The subtle differences in signatures are what allow the separation of multiple weed species as seen in Figure 6.

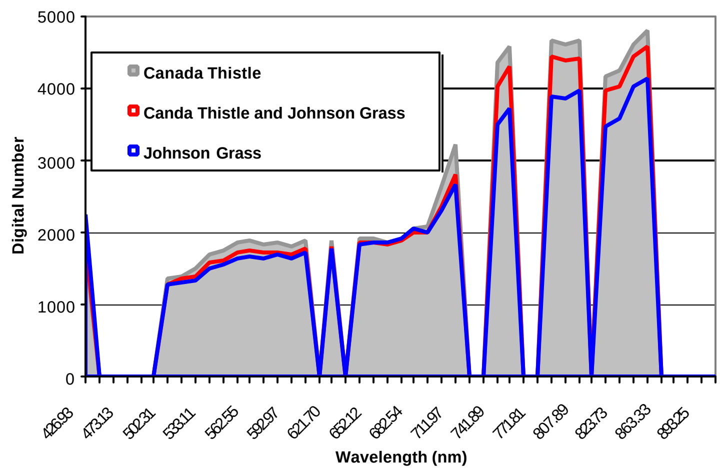

Figure 6. Pure and mixed weed species spectral signatures at 2m resolution.

To date we have seen success in mapping weeds in fields at multiple resolutions. Determining weed species via hyperspectral imagery however, continues to be difficult and remains the focal point of our hyperspectral research. It is believed that utilizing other regions of the electromagnetic spectrum, changing the number and placement of bands, and improving computer algorithms will improve hyperspectral weed species mapping capabilities.

ECONOMIC CONSIDERATIONS

Economic Assessments

A goal of this investigation, beyond the development of technical processing methods and techniques, was to measure the cost effectiveness of information derived from hyperspectral data. Information provided from imagery has utility to a farmer both as a long-term digital record and a short-term indicator of crop conditions that may impact yield and require immediate attention. Some of the long-term and intrinsic benefits of the information are difficult to quantify such as the effects on the local habitat from reducing chemical use or, a dollar value for the ability to reference year-by-year crop vigor. For these reasons, the focus of this investigation was on the short term, quantifiable benefits. For the purposes of this paper, the potential savings in dollars to a farmer in the treatment of weeds was estimated based on using the imagery to locate weeds and determining the area requiring treatment.

Typical weed management for the study fields involves spraying the entire field when weed infestations within the field reach an extent that a crop scout or farmer determines will significantly impact yield. A weed location map produced from the imagery provides a quantification of weed extent as well as information on where spraying is needed. This information provides an opportunity to save on the cost of treatment by applying treatment only where required. To gain insight as to how this imagery could be of economic value consider the example of the soybean field shown in Figure 7.

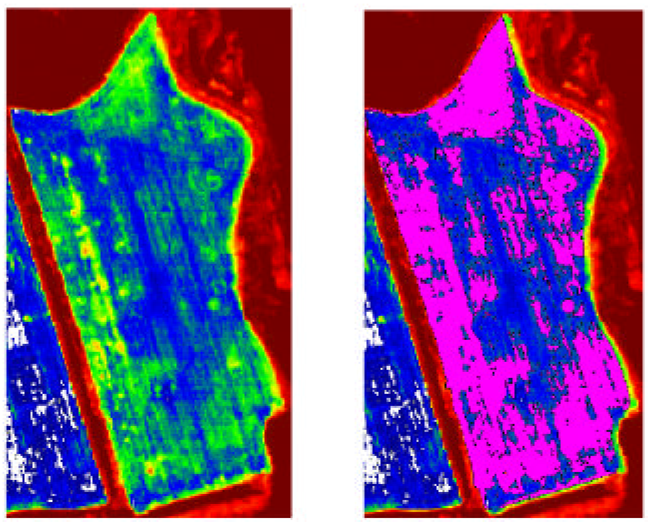

Figure 7: May 2m classification for Field 57A showing classified image (left) with areas of healthy soybean in blue and areas of weed infestations in green to yellow. Right image is "Spray/Do Not Spray" map.

The total acreage for this soybean field is 24.1 acres. The entire field was treated with a series of post-emergence herbicides at a total material cost of $32.40 per acre not including cost for labor and equipment. Required herbicide inputs for treatment of the entire field therefore cost $780.84.

The total area recommended for spraying due to indication of weed presence, (represented in purple) is 13 acres. Treating only the 13 acres with weeds present would cost $421.20, representing a total savings of $359.64 or $14.92 an acre. The labor and equipment cost, estimated at $5/acre, would only be saved in larger fields where entire sections were weed free.

To take advantage of these savings, VRT for herbicide application must be available. Improvement in VRT would be required to load weed maps derived from imagery into GPS controlled spraying equipment. These savings could only be realized in conjunction with the technology to apply treatment only where required.

As the investigation falls under "R&D," it is difficult to accurately estimate of the cost of producing the imagery and furthermore, potential savings after technology cost. However the example does show the application of remote sensing imagery to precision farming is worthy of further application and economic study. Further research is also required to investigate the potential for imagery to be used in accurately identifying specific weed types for remote herbicide prescription as well as the ability to process the imagery within 24 hours of collection and deliver information to personnel in the field using wireless devices.

Payoff of the Technology

The technologies discussed here are not yet beneficial for every farmer and every crop. Many factors will determine when remotely sensed data will become an integral part of farm management decision-making. Until that time it will continue to be expensive. To determine whether precision weed control technologies might improve the bottom line, it is important to develop economic thresholds for weed management plans. Thresholds will help to ease the decision of when and when not to employ such technologies.

Table 2. Economic threshold questions.

Precision Weed Control: Economic Threshold Questions
1. Where are the weeds and what species are they?
2. What stage of development are weeds in relation to the crop?
3. What impact will weeds have on yields if not controlled?
4. Will weeds affect other fields, livestock, or crop quality?
5. What is the cost of controlling the weeds?
6. What is the cost of the technological inputs?
7. What are the expected benefits? (Improved Yields, Decreased Costs, etc.)
8. What is the Estimated Cost/Benefit ratio?

The Estimated Cost/Benefit ratio is the most important factor in weed control decision making. Because whether precision weed control technologies improve your Cost/Benefit ratio via better timing of your pre-emergent spray or improve decision making on post-emergent spraying, they can potentially save a lot of time and money.

CONCLUSION

Hyperspectral imagery does have the potential to identify specific species of weeds but will require more research and time to create the necessary information for accurate delineation of weed infestations, identification of species, and determination of economic cost/benefits. In the future this will be a new form of management making possible the identification of many problems faced by farms every growing season. There are savings to be made but the cost of achieving those saving remains out of touch by the majority of producers.

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